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EFFECT OF MANGANESE ON THE DYNAMIC
RECRYSTALLIZATION BEHAVIOR OF TITANIUM-BEARING
MICROALLOYED STEELS

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SUMMARY

The effect of Mn in the range 0.5 to 1.6 wt.% on the dynamic recrystallization behavior of austenite was investigated in three 0.1 wt.% Ti steels. Compression tests were carried out in the temperature range 925-1225°C at a constant strain rate of $2.8 \times 10^{-2} \text{ s}^{-1}$. Dynamic recrystallization-time-temperature (RTT) curves were constructed from the peak strains of the flow data. The occurrence of precipitation at the lower temperatures led to breaks in the RTT curves, and therefore to an increase in the recrystallization start times. The results indicate that increasing the Mn level from 0.5 to 1.6% shifts the RTT curves to the right slightly, i.e. to longer times. The greater retardation of recrystallization with respect to a similar plain carbon-manganese steel is attributed to the presence of Ti in solution. Below the break temperature, a further component of retardation arises from the dynamic precipitation of TiC.

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FOREWORD

This report summarizes the progress of research done under CANMET/DSS Contract No. 20SU.23440-0-9171: "The Effects of Molybdenum, Titanium and Niobium on the Hot Working (Controlled Rolling) of Line-pipe Steels - Phase I", during the period of June 1, 1981 to March 31, 1982, by Professor J.J. Jonas, Dept. of Mining and Metallurgical Engineering, McGill University.

The overall objective of three proposed phases of the research is to determine the effects of microalloying elements Mo, Nb and Ti on the rates of recrystallization, grain growth and precipitation in terms of controlled-rolling practice of high-strength line-pipe-grade steels, with a view to enabling reduction of microalloying costs and improvement of steel properties. The basic information provided by this research will be used to optimize steel composition and roll pass scheduling in related CANMET research and in Canadian production of steel strip, plate and linepipe.

Dynamic recrystallization and precipitation kinetics were determined for three 0.1% Ti steels with Mn levels of 0.5, 1.1 and 1.6%, and were compared with the kinetics for plain carbon, V, Mo and Nb steels. Increasing the Mn level decreases the TiC precipitate solution temperature, and therefore increases the precipitation start time. Titanium at the 0.1% level is slightly more effective in solution than 0.035% Nb on retardation of dynamic recrystallization. In the vicinity of 1075°C, TiC precipitation further retards dynamic recrystallization. However, ranking of microalloying effectiveness on an equal atom fraction basis places Nb ahead of Ti.

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INTRODUCTION

Titanium is commonly added to low carbon steels at the 0.015% level to prevent grain coarsening during reheating or welding. At higher concentrations, e.g. 0.1 to 0.2%, titanium acts to increase the yield strength and toughness, largely by refining the ferrite grain size (1 - 3). However, the detailed role of titanium in producing austenite 'pancaking', and thus in refining the ferrite microstructure, is not well understood, as it includes both solute and precipitate components. The present investigation was therefore carried out to determine the extent of the solute retardation of austenite recrystallization in such materials, and to distinguish this from the retardation produced by the precipitation of TiC. By selecting steels with manganese levels of 0.5, 1.1 and 1.6%, the retardation due to manganese in solution was also established.

EXPERIMENTAL MATERIALS AND METHODS

A series of three 0.1% Ti steels was prepared in the Physical Metallurgy Research Laboratories of the Department of Energy, Mines and Resources, Ottawa. The chemical compositions of these steels are shown in Table 1, from which it can be seen that the two higher Mn steels contained 0.1% C, while the 0.5% Mn steel had a reduced carbon concentration of 0.06%.

Samples were prepared with the compression axis along the rolling direction of the as-received plates. To eliminate the rolling texture, the specimens were vacuum annealed at 1000°C for two hours and water quenched. Each sample was subsequently austenitized at 1260°C for 30 minutes in an argon atmosphere and cooled to the test temperature at 1°C/sec. The initial austenite grain sizes resulting from this treatment were approximately 110 μm for the two higher manganese steels, and about 120 μm for the 0.5% Mn steel.

In order to estimate the amount of titanium in solution and therefore available to form TiC, two extreme cases were considered. These are identified as Ti_{min} and Ti_{max} in Table 1, and were calculated from

$$\% \text{ available Ti}_{\text{min}} = \% \text{Ti} - \frac{48}{32} \% \text{S} - \frac{48}{14} \% \text{N} \quad (1)$$

Here, all of the nitrogen and sulphur present are assumed to combine with titanium during solidification (4). In the presence of less than 0.1% Ti,

most of the sulphur can be taken up by the manganese (2), leading to the relation

$$\% \text{ available Ti}_{\text{max}} = \% \text{Ti} - \frac{48}{14} \% \text{N} \quad (2)$$

The TiC solution temperatures based on these alternative titanium levels are also shown in Table 1. A more detailed account of the effect of manganese on these temperatures is under preparation (5). Compression tests were carried out at a constant true strain rate of $2.8 \times 10^{-2} \text{ s}^{-1}$. Isothermal tests were performed at 1225, 1160, 1100, 1025, 975 and 925°C. Further aspects of these experiments are also described in Reference 5.

RESULTS

A typical set of flow curves for the 0.5% Mn steel is shown in Fig. 1. At 1225°C, dynamic recrystallization is readily initiated, as indicated by the relatively low value of the peak strain ϵ_p . With decreasing temperature, the value of ϵ_p increases by about 10% per 50°C down to 1000°C. Below that temperature, the rate nearly doubles to 18% per 50°C. This break in the rate of increase in the peak strain is due to the dynamic precipitation of TiC, as will be seen below.

The small effect on the flow behavior of the 0.1% Ti steel of the three different manganese concentrations is displayed in Fig. 2. At 1225°C, three cycles of dynamic recrystallization are observed, as indicated by the three local maxima in the curves (6,7). The peak strain is reached earliest in the 1.1% Mn steel. The other two steels have similar peak strains, although the peak stress values differ to a greater degree. As expected, the 1.6% Mn steel has the largest peak stress; the intermediate position of the 0.5% Mn material can be attributed to the coarser grain size associated with this alloy. The dynamic recrystallization start and finish times (R_s and R_f respectively) can be calculated from the strain rate $\dot{\epsilon}$ as follows (8):

$$R_s = \epsilon_p / \dot{\epsilon} \quad \text{and} \quad R_f = \epsilon_f / \dot{\epsilon} \quad (3) \text{ and } (4)$$

Here, for simplicity, dynamic recrystallization is assumed to begin at ϵ_p , even though the ratio ϵ_c / ϵ_p , where ϵ_c is the critical strain for the onset of recrystallization, has been demonstrated by Sakai and co-workers (6) to vary with strain rate and temperature. The completion strain ϵ_f , defined in Fig. 2, corresponds to the end of the first cycle of recrystallization, and

is equal to the steady state strain at high strain rates or low temperatures (e.g. at or below 1100°C).

The dynamic RTT curves determined in this way are displayed in Fig. 3, together with some results for a reference plain carbon steel (9). Superimposed on this plot are the preliminary dynamic precipitation-time-temperature (PTT) data for the three steels determined in the precipitation part of the present study (5). At all temperatures, the plain carbon steel recrystallized most rapidly. In comparison with this reference material, the addition of 0.1% Ti has two effects, depending on the temperature range. The first is a solute effect, observed at temperatures above the TiC solution temperature, and also below this temperature, as long as recrystallization is initiated prior to precipitation (9, 10). At sufficiently low temperatures, where the supersaturations are larger, dynamic precipitation is initiated first and produces an additional component of retardation beyond that due to solutes alone. The solute controlled behavior is extrapolated to lower temperatures in Fig. 3, as indicated by the broken lines. The solute retardation due to the addition of 0.1% Ti to a 1.4% Mn plain carbon steel is considerable (see the curve for the Ti-1.6% Mn steel). At the lower manganese concentrations, this effect is slightly reduced. The reversal in the order of retardation produced in the 0.5% and 1.1% Mn steels is probably due to the slightly larger grain size in the former material (see above), as shown by Sah and co-workers (11) and Sakai and co-workers (6).

The demarcation between the solute and precipitate controlled regions is indicated, in Fig. 3 by circles at the intersections of the RTT and PTT curves. The transition temperatures are in the vicinity of 1075°C for the three steels, although the intersection temperature is lowest for the 1.6% Mn steel, in agreement with its slower precipitation kinetics. The range of R_f times for these steels is also illustrated in Fig. 3. It is noteworthy that these times correspond reasonably closely to the precipitation finish times (P_f). The R_f times for the plain carbon steel are approximately equal to the R_s times for the Ti-1.6% Mn steel, but are omitted for simplicity. Thus, it is evident that the addition of 0.1% Ti also delays the end of recrystallization and that, on a log-time basis, this delay is of similar magnitude in the solute controlled region.

DISCUSSION

The R_s times for the three titanium steels show small but measurable differences at the present manganese levels. The more important effect of manganese appears to be on the precipitation kinetics (5). There, the steel containing the lowest manganese addition has the shortest P_s time. This situation is similar to the effect of manganese on the precipitation kinetics of Nb(CN) (9,12) and VN (13) in austenite, where the addition of manganese decreases the precipitate solution temperature. The solution temperatures indicated in Table 1 and Fig. 3 do not take this effect into account. Thus, the 0.5% Mn steel is expected to have a higher solution temperature than the basic 1.3% Mn level on which the calculation is based.

The dynamic RTT curves for the plain carbon and the Ti-1.6% Mn steel are compared with those for three other microalloyed steels in Fig. 4. It can be seen that the addition of 0.115% V to a plain carbon steel produces a small but measurable delay in the onset of recrystallization. This effect is due to the presence of vanadium in solid solution (13). The addition of 0.30% Mo (9), which also acts only as a solute, produces a much larger delay. The solute retardation resulting from a 0.035% Nb addition is similar to that of the Mo at most temperatures. The effect of 0.1% Ti is only slightly larger than that of 0.035% Nb. In this case, however, when the results are normalized to an equal atom fraction, Nb is seen to have a stronger influence than Ti. The rank order of solute retardation can be expressed in terms of the following solute retardation parameter (S.R.P.) (8):

$$\text{S.R.P.} = \log(1 + \Delta t_x / t_{\text{ref}}) \times \frac{0.1}{\text{at.\%}x} \times 100 \quad \%$$
 (5)

Here, t_{ref} is the R_s time for the reference plain carbon steel, and Δt_x is the solute retardation in time resulting from the addition of element x. In the solute effective region, $\Delta t_x = R_s^x - R_s^{\text{Pl.C.}}$; at lower temperatures, this time difference is based on an extrapolation of the solute controlled curve. According to this description, Nb produces the largest effect (55%), followed in decreasing order by Ti (13%), Mo (10%), V (3%) and lastly Mn (0.2%). This rank order is in agreement with the combined electronic/atomic diameter model proposed earlier (9,12). Such a model appears to agree more closely with the relative retardations of recrystallization than rationalizations based solely on solute atomic size difference with respect to the solvent (3). For example, although Al, Nb and Ti have similar size differences with respect to Fe, their effects on retarding recrystallization vary considerably.

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Table 1 Compositions (wt. %) and Carbide Solution Temperatures (°C)

Steel	C	Mn	N	S	Total Ti	Available Ti _{min}	Available Ti _{max}	T _{sol} ^{min*}	T _{sol} ^{max*}
0.5% Mn	0.06	0.48	0.006	0.007	0.120	0.089	0.099	1120	1135
1.1% Mn	0.10	1.07	0.006	0.008	0.110	0.084	0.096	1180	1195
1.6% Mn	0.10	1.60	0.005	0.009	0.115	0.084	0.098	1180	1200

Al = 0.01 to 0.025%, Si = 0.12 to 0.29%

*Not corrected for the effect of manganese and silicon on the activity of carbon.

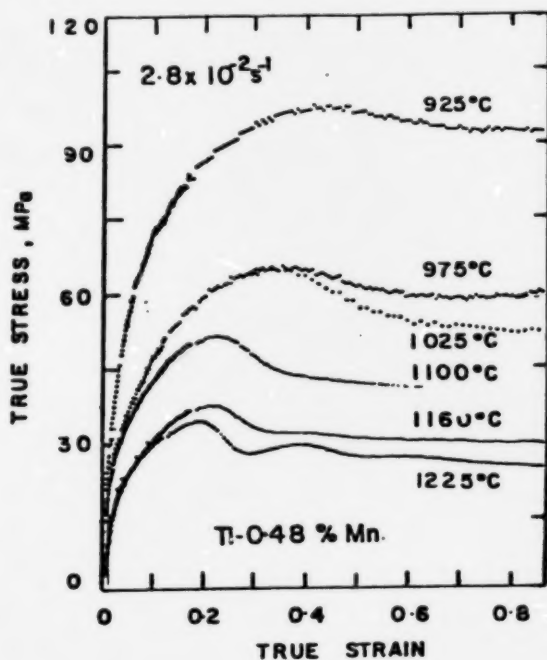


Fig. 1. Effect of temperature on the flow behavior of the Ti-0.5% Mn steel at a strain rate of $2.8 \times 10^{-2} \text{ s}^{-1}$.

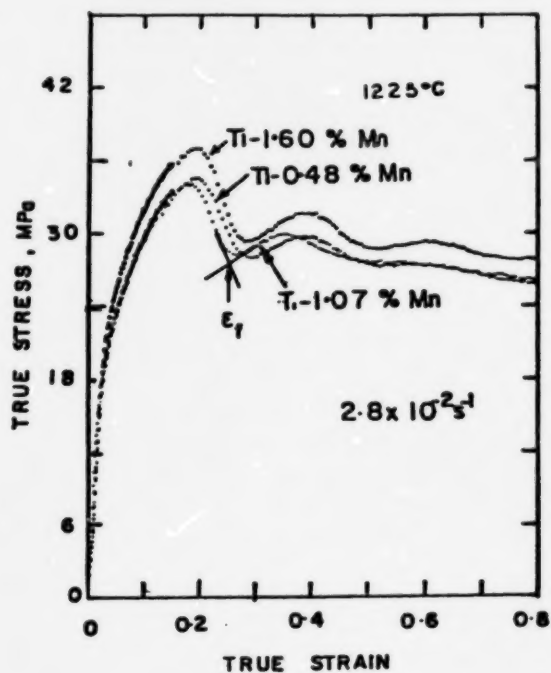


Fig. 2. Flow curves for the 0.1% Ti steels tested at 1225°C and a strain rate of $2.8 \times 10^{-2} \text{ s}^{-1}$. The peak stress and strain are highest in the Ti-1.6% Mn steel.

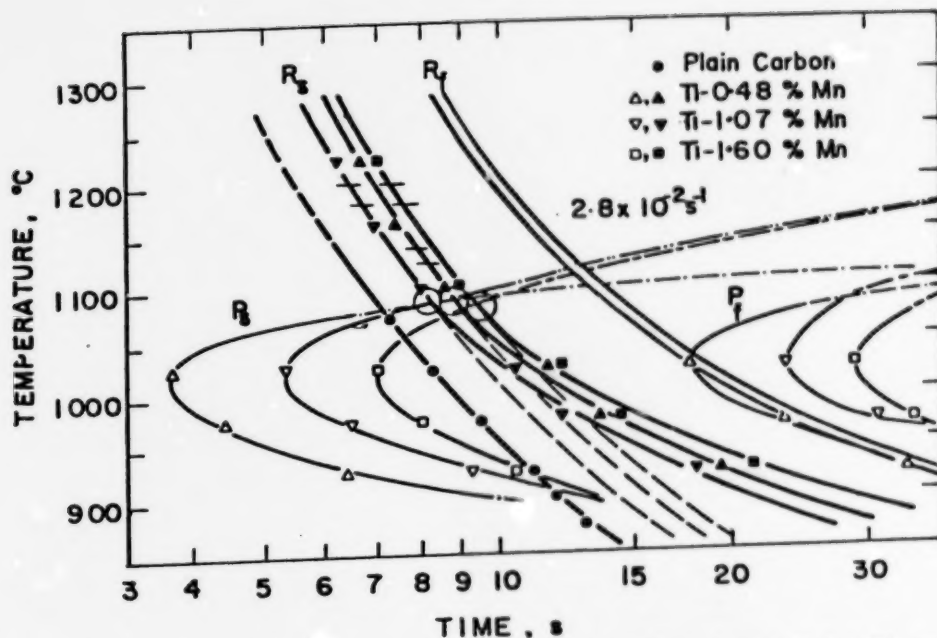


Fig. 3. Dynamic RTT and PTT curves for the three 0.1% Ti steels and a reference 0.06% C - 1.43% Mn steel. The titanium steels show appreciable solute retardation of recrystallization above the solution temperatures, T_{sol} . Below T_{sol} , there is a further delay due to TiC precipitation.

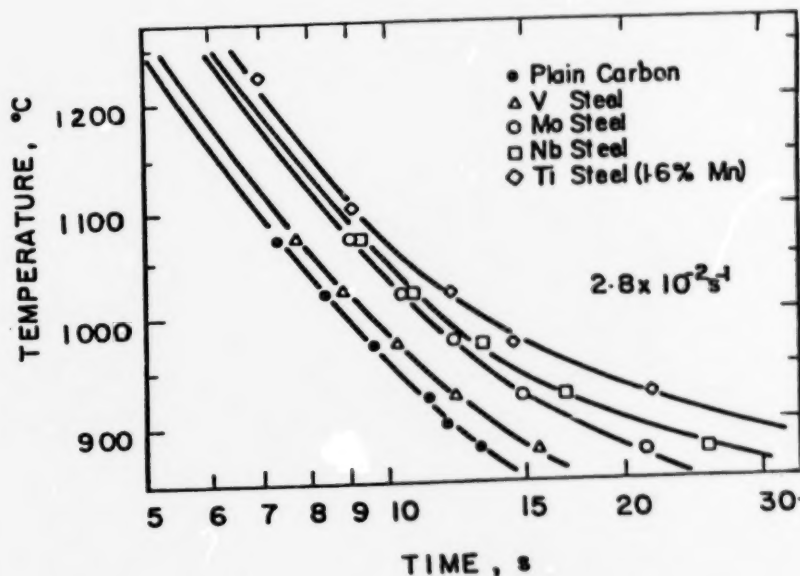


Fig. 4. Dynamic RTT curves for the reference material and four microalloyed steels. The onset of recrystallization is most delayed by the addition of 0.1% Ti and, in decreasing order, by that of 0.035% Nb, 0.30% Mo and 0.115% V (9).

